

AIR PRODUCTS

This presentation does not contain any proprietary or confidential information.

A group of diverse children are shown from the chest up, arranged in a circle and holding a large, realistic globe of the Earth. They are all smiling and looking towards the camera. The background is a solid blue color. The text is overlaid on the left side of the image.

Hydrogen. Fueling a Cleaner Future.

Validation of an Integrated System for a Hydrogen-Fueled Power Park

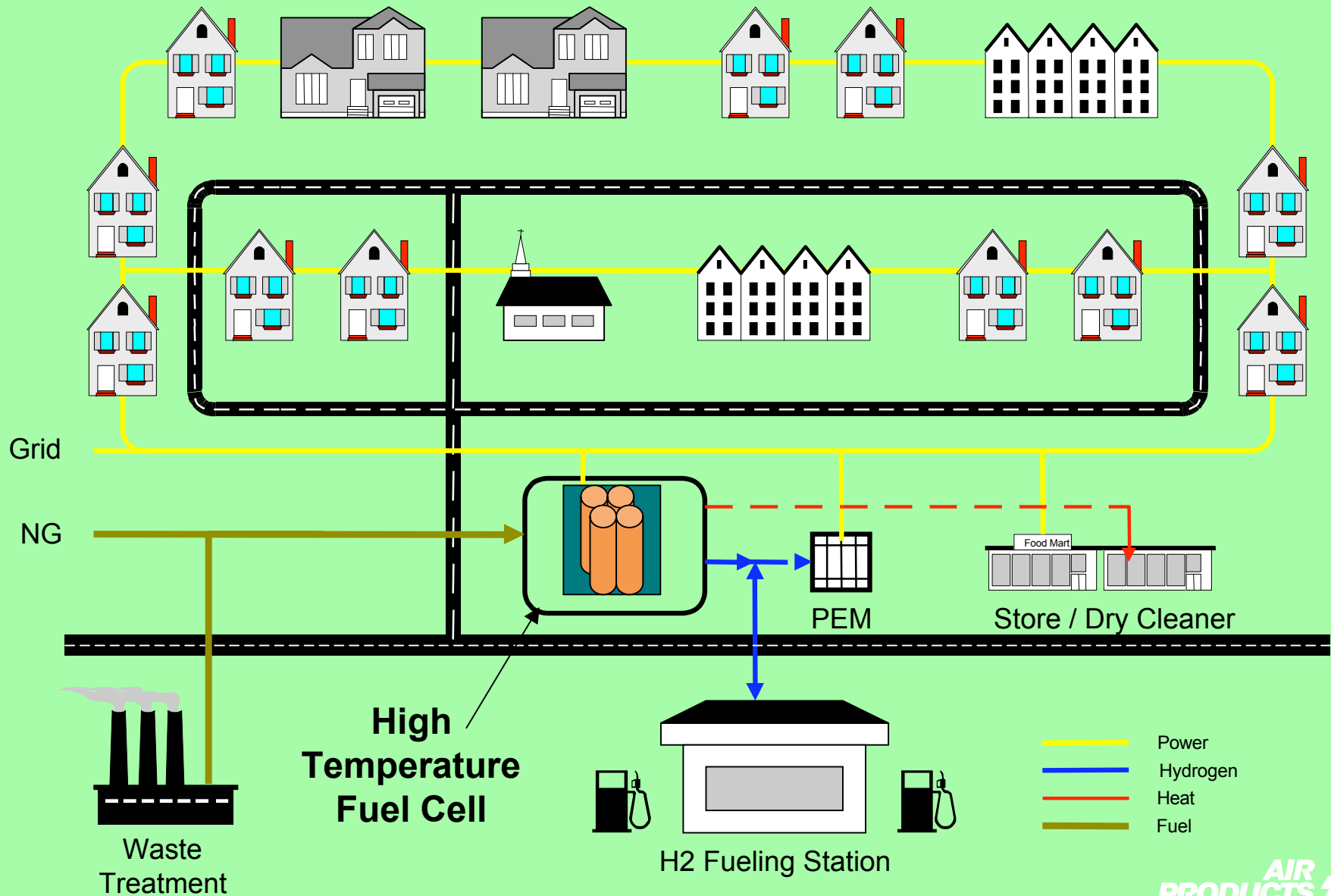
Greg Keenan
Air Products and Chemicals, Inc.

Merit Review and Peer Evaluation
26 May 2004

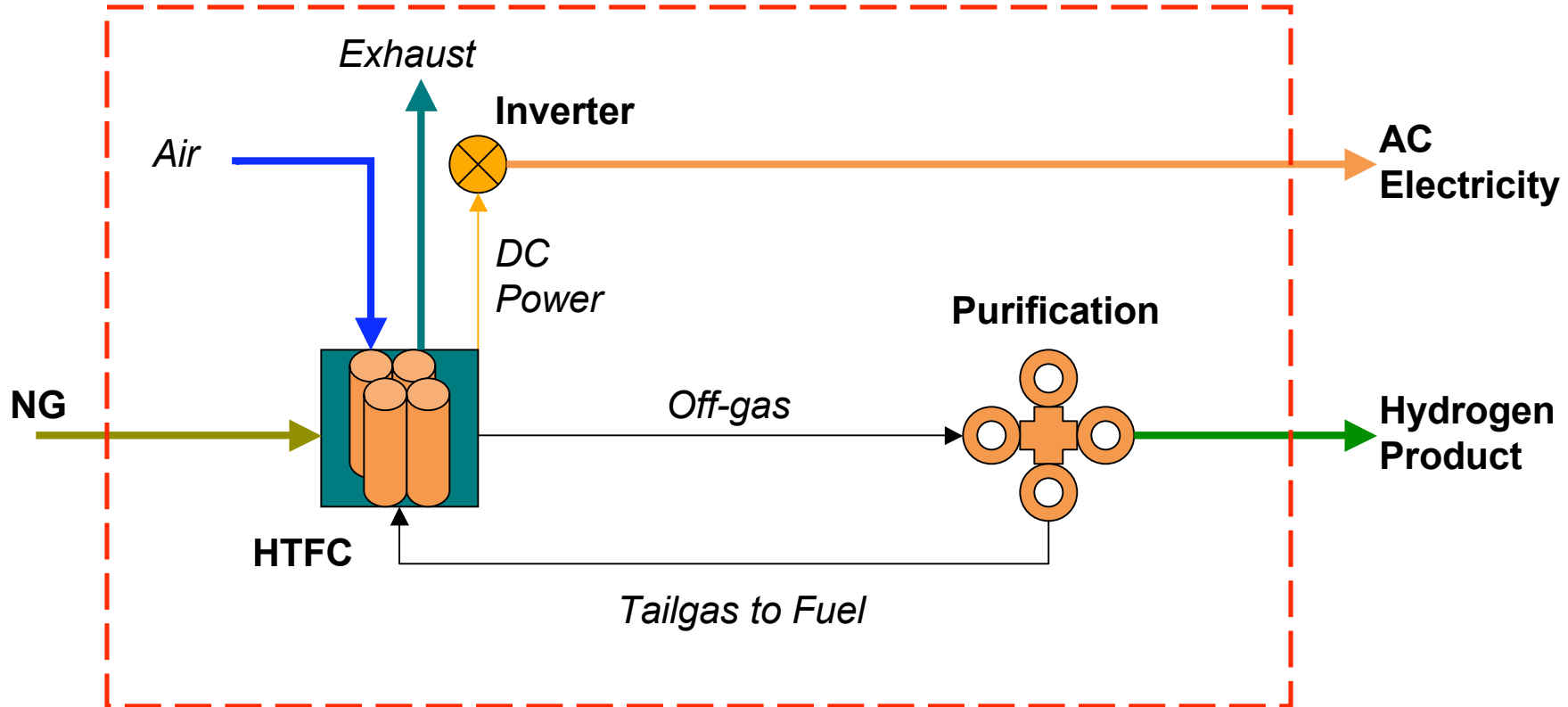
Objectives (FY04)- Phase 1B

- **Complete a feasibility, technical, and economic analysis to determine the optimal fuel cell system for the co-production of power and hydrogen from natural gas (energy park)**
 - **Reformer / PEM System**
 - **High Temperature Fuel Cell (HTFC)**
- **Optimize the system for lowest total energy price**
- **Develop a cost estimate to demonstrate a prototype natural gas based energy park at a suitable site**

PowerPark Concept



High Temperature Fuel Cell (HTFC) Co-production



Potential Co-Production Efficiency (LHV): 55 - 60%

Benefits of HTFC Co-Production

- High efficiency
- Low emissions
- Potential to use waste hydrocarbons as energy source
- Multiple product slate (power, hydrogen, & heat)
 - Improves capital utilization
 - More flexible pricing options- 2 or 3 Levers
- Fuel cell / fuel cell hybrid option
 - Efficient cycle – (potential for > 60%)
 - No turbine- potential for higher reliability and less maintenance

Distributed Power and Hydrogen for Industry...



Siemens Westinghouse

Electricity
Hydrogen
High Grade Heat



Petrochemicals



Glass



Electronics



Utilities

Distributed Power and Hydrogen for Consumers...



FuelCell Energy DFC-300

Power

Heat



The Plaza at PPL Center, Allentown

H2



Budget

- Total Project Budget:
 - \$1.391 MM
- Cost Sharing:
 - DOE - \$0.695 MM
 - APCI and Partners – balance.
- FY2004 Funding
 - \$ \$100 k Obligated by DOE

Technical Barriers and Targets

● DOE Technical Barriers

- Technical Validation (Section 3.5.4.2 of HFCIT Program Report), Task #4.
 - B. Storage
 - C. H₂ Refueling Infrastructure
 - I. Hydrogen and Electricity Coproduction

● DOE Targets

- H₂ Production (Table 3.1.2 of HFCIT Program Report), Task #3.
 - Cost of H₂:
 - \$3/kg 2005
 - \$1.50/kg 2010

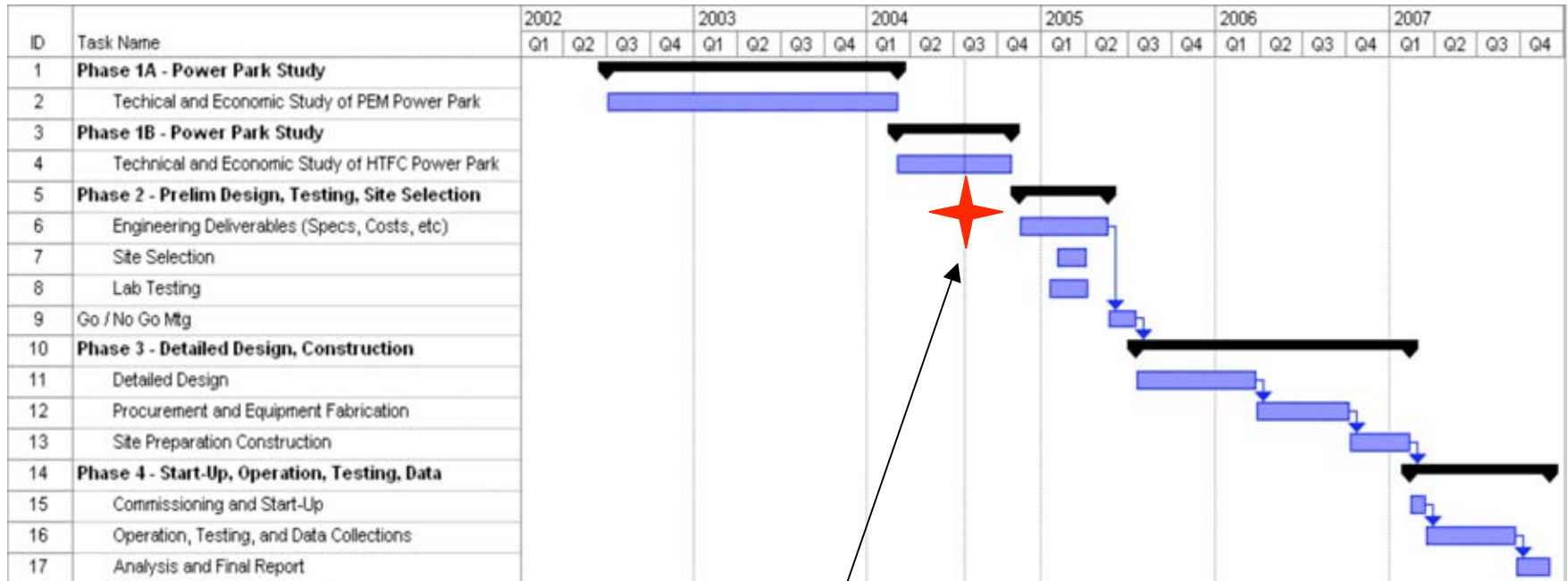
Approach: Co-production Analysis

- **Phase 1B- Process and Economic Analysis**
 - **3 HTFC technologies evaluated**
 - 2 Solid Oxide Fuel Cells (2 different geometries)
 - 1 Molten Carbonate Fuel Cell
 - **Each HTFC technology was matched with the appropriate purification technology selected by Air Products**
- **HTFC Vendors Provided:**
 - Fuel Cell Performance Projections
 - Fuel Cell Cost Projections
 - Flow Diagrams
 - Process Data
- **Air Products Provided:**
 - Purification design, performance and cost projections
 - Overall process and economic analysis

Safety Reviews and Training

- APCI has >40 years experience in safe design, construction, & operation of H2 plants.
- Leader in Management of Change, Near Miss Reporting, and Quantified Risk Assessment Procedures
- PHR: Phase 2
- HAZOP: Phase 3
- All applicable industry codes will be followed
- APCI participates in SAE, ICC, ISO, HFPA, IETC, and EIHP2 committees

Project Timeline



Today: APCI & DOE Go- No-Go Decision

Phase 1A Conclusions- FY03

- **Small Reformer/PEM System (w/ current PEM technology)**
 - Low commercial potential for distributed continuous power generation with natural gas as a feedstock.
 - Don't recommend a Phase II demonstration with PEM
- **PEM Niche Market Opportunities: Pipeline/Offgas (Back-up)**
 - Economic in limited geographic region
 - Potential in non-attainment areas (low emissions)
 - Low noise
 - Spinning reserve
- **Co-production of Power and Hydrogen using High Temperature Fuel Cells**
 - High temperature fuel cells have greater potential than PEM for distributed power
 - Energy Station- Co-production of Hydrogen and Power
 - Distributed Generation- Hybrid Fuel Cell Cycle
 - Recommend further review- Phase 1B

Phase 1B Conclusions- FY04

- **High temperature fuel cells configured to co-produce hydrogen have the ability to meet the DOE hydrogen targets as specified in the multi year plan while producing power for less than 0.10 \$/kW**
- **Both molten carbonate and solid oxide fuel cells can be designed for co-production**
 - Co-production efficiencies were similar- 55%-60% (LHV)
 - Both have the potential to meet the DOE targets while producing power for less than 0.10 \$/kW
- **Engineering development required for co-production**
 - Recovering and conditioning off-gas
 - Purification of hydrogen
 - System integration
 - Optimization of co-produced products
- **Recommend proceeding with engineering development, design, and demonstration of the economic viability of a combined electric power and hydrogen production application**

HTFC Co-Production Economics

	2005	2010	2015
Hydrogen, kg/day*	690	690	690
Net Electricity, kw	>1.5 MW	>1.5 MW	> 1.5 MW
HTFC Cost, \$/kW AC w/o H2	2250	1200	800
Natural Gas Costs, \$/mmbtu*	4.00	4.00	4.00
Production Volume, units/year*	100	100	100
Fueling Utilization*	90%	90%	90%
Capital Factor*	0.11	0.11	0.11
Base Energy Price			
Hydrogen Price, \$/kg	2.97	2.15	1.88
Power Price, \$/kwh	0.07	0.05	0.05
Fueling Scenario			
Hydrogen at the Pump, \$/kg*	3.00	1.50	1.50
Station Allocation, \$/kg*			
Compression, \$/kg H2*	-0.29	-0.24	-0.24
Storage & Dispensing, \$/kg H2*	-0.19	-0.11	-0.11
Hydrogen Production Price, \$/kg	2.52	1.15	1.15
Power Price, \$/kwh	0.08	0.07	0.06

*Assumptions from the DOE Multi-Year Research, Development and Demonstration Plan, Table 3.1.2, page 3- 10, Draft 6/3/03.

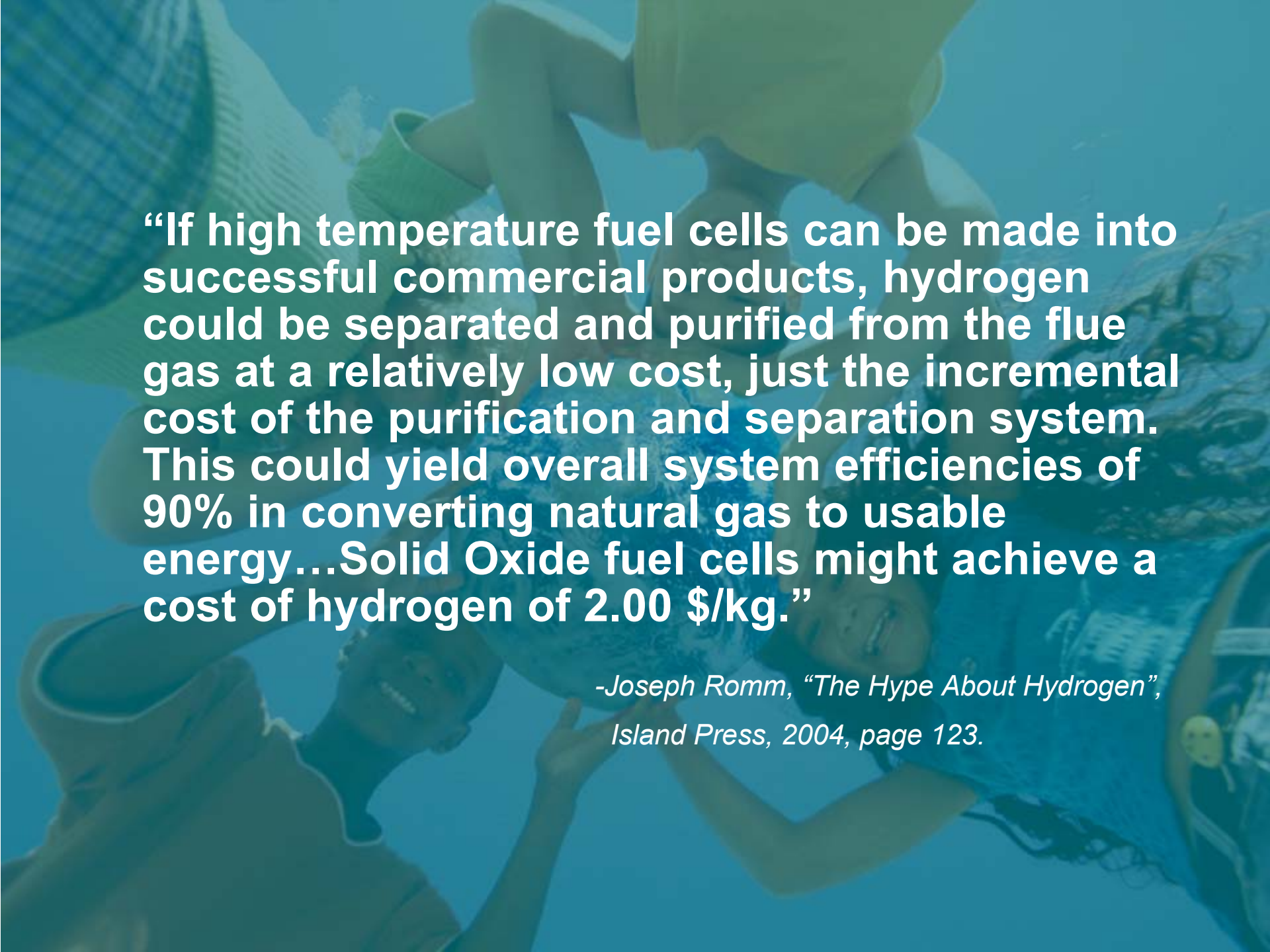
Future Work: Required Engineering Development

- HTFC modifications to recover off-gas
- Off-gas conditioning
- Hydrogen purification
- System integration
- Steady state vs. dynamic response
- Optimization of co-produced products

Development work applicable to both MCFC and SOFC

Proposed Forward Program

- **Develop and demonstrate the technical and economical viability of a HTFC co-production system.**
- **Program Forward**
 - HTFC Partner Selection
 - Phase 2: Preliminary Design, Engineering Development, Firm Bid Estimate, and Site Selection
 - **DOE/APCI GO / No-GO**
 - Phase 3: Detailed Design and Construction
 - Phase 4: Operation, Testing, Data Collection



“If high temperature fuel cells can be made into successful commercial products, hydrogen could be separated and purified from the flue gas at a relatively low cost, just the incremental cost of the purification and separation system. This could yield overall system efficiencies of 90% in converting natural gas to usable energy...Solid Oxide fuel cells might achieve a cost of hydrogen of 2.00 \$/kg.”

*-Joseph Romm, “The Hype About Hydrogen”,
Island Press, 2004, page 123.*

Thank you

Special Thanks to:

DOE- Chris Bordeaux, Sig Gronich

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